

# THE AGE OF THE GALACTIC DISK

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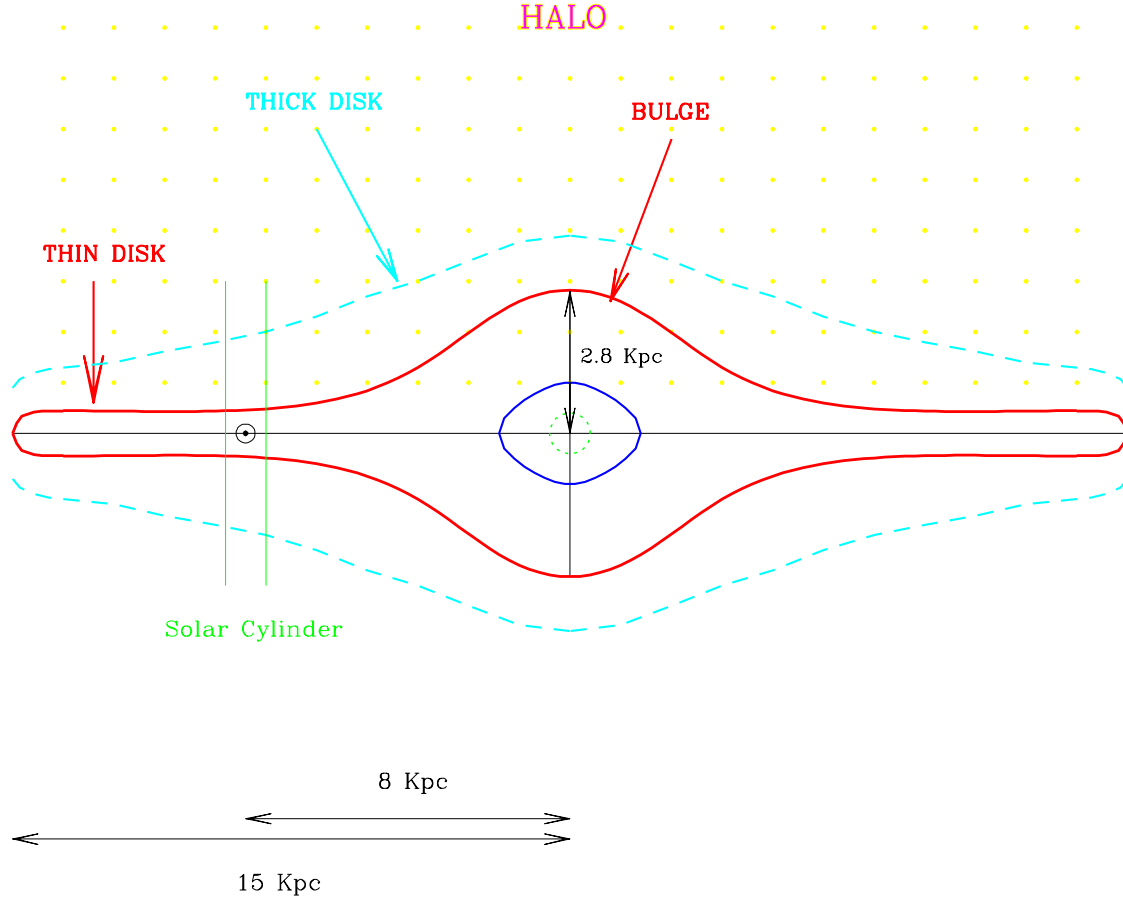
**Abstract.** I review different methods devised to derive the age of the Galactic Disk, namely the Radio-active Decay (RD), the Cool White Dwarfs Luminosity Function (CWDLF), old open clusters (OOC) and the Color Magnitude Diagram (CMD) of the stars in the solar vicinity. I argue that the disk is likely to be 8-10 Gyr old. Since the bulk of globulars has an age around 13 Gyrs, the possibility emerges that the Galaxy experienced a minimum of Star Formation at the end of the halo/bulge formation. This minimum might reflect the time at which the Galaxy started to acquire material to form the disk inside-out.

## 1. Introduction

Disks are quite common structures in the Universe. According to the classical theory of White & Rees (1978) spiral galaxies are considered the seeds of galaxies assembly due to gas cooling inside spinning dark matter halos. Apart from spirals, disks are seen also in the center of giant ellipticals; damped Lyman  $\alpha$  clouds are commonly believed to be gaseous disks. Finally, S0 galaxies are expected to be disk galaxies depauperated of their gas.

However galaxian disks are fragile structures. N-body simulations convincingly show that the merging of two equal mass galaxies is fatal for disks. They are simply destroyed. The observational counterpart is represented -just to mention a source- in the IRAS database, which shows many disk on the way to be destroyed by major mergers.

Since our disk appears almost undamaged, this means that it did not suffer from strong mergers since its formation, and that its past life was relatively quiet. Of course we cannot forget that our disk has a warp, and that presently a dwarf galaxy - Sagittarius - is going to merge with our



*Figure 1.* A sketch showing the vertical structure of the Galaxy. The solar vicinity is shown as a cylinder with a radius of 1 kpc.

Galaxy.

Just how the past life was quiet can be gauged by the ability of small galaxies to heat or thicken the disk. Quinn et al (1993) pointed out that even

satellites with masses of order 5% – 10% of the disk mass can thicken the disk by a factor of two or more if they dump all of their available orbital kinetic energy into the disk. Hence the presence of disks with scale heights less than a few hundred parsecs (*thin disks*) implies the absence of even minor encounters over the age of the *thin disk*. Nonetheless it may be possible for disks formed early in the lives of spirals to have been heated by satellites forming a thick disk within which a new *thin disk* was allowed to form. If this was the case, an estimate of the *thin disk* age can fix the time at which the last encounter occurred.

The acute fragility of disks is a very important constraint on the evolution of the environment of protogalaxies that develop into current spirals. Either they were born in isolation (low density environment) or they managed to remove all potentially disk-disturbing debris early enough that a normal disk had time to form. It is clearly very interesting to look from our favorite observational point, the solar system, at the disk population to try to establish its age. This is important to constrain the zero point of chemical evolution models, the relationship between the disk and the other galaxy components, and to fix a rough chronology for the disk development and origin.

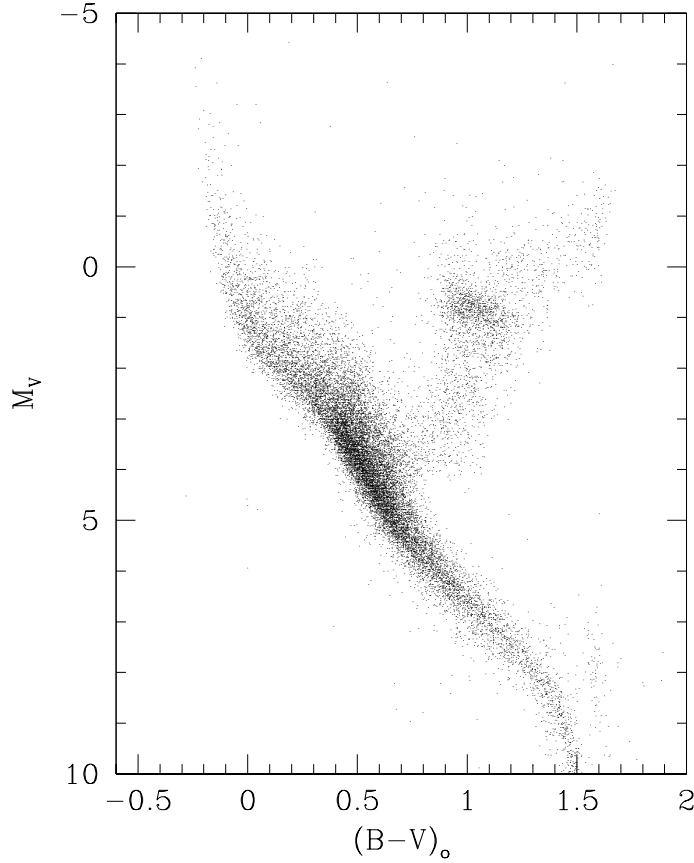
## 2. Age indicators

In the following I shall discuss five different methods devised to obtain an estimate of the age of the galactic disk, discussing their feasibility, robustness and limitations.

I shall start making a crucial point. Most methods to infer the age of the galactic disk pretend, or try, to give an age estimate for the entire disk (or even for the Galaxy as a whole), by using age indicators located in the near solar vicinity (see Fig. 1). Whether the solar neighborhood is really representative of all the disk is an open question, which does not hold only for this particular issue - the age of the disk -, but more generally for determining the global chemical evolution and the SF history of the galactic disk looking at nearby indicators (Carraro et al 1998). At present only old open clusters (although the sample is rather poor) can be used to derive an estimate for the age of a significant portion of the galactic disk. Moreover all the methods devised to address this topic make use of indicators located well inside the *thin disk*. Therefore I am going to discuss the age of the galactic *thin disk* (Gilmore et al 1989).

### 2.1. COOL WHITE DWARFS LUMINOSITY FUNCTION

The idea that the coolest white dwarfs (WD) can be used to determine the age of the local galactic disk dates back to Schmidt (1959). His idea



*Figure 2.* The CMD of nearby stars from Hipparcos. The red envelope of the subgiant region is used to set a minimum age of the galactic disc.

was the following: if we find the coolest white dwarf (just looking at the downturn of their luminosity function) and measure their cooling time, we can find the age of the disk just adding to this time the lifetime of the WD progenitor. Moreover WDs are easy to be modelled, much easier than Main Sequence (MS) stars (Mestel 1952). At that time it was not possible to detect the turn-down, and the idea failed. Moreover some uncertainties in the models arose, in particular the crystallization. In detail, at decreasing temperature ions start to crystallize, and the energy necessary to maintain the ions lattice causes the WD to cool to invisibility very rapidly.

More recently Winget et al (1987) succeeded to find the turn-down, and since then many authors built up CWDLF (Leggett et al 1998). In addition theorists now agree that the onset of rapid cooling is not reached for the

dominant stellar mass in the WD population ( $0.6M_{\odot}$ ) until well below the luminosity of the observed shortfall. The most recent work is from Knox et al (1999). They find 52 CWDs using common proper motion binaries. Their sample is the only complete one both in luminosity and in proper motion. The resulting LF (see their Figs. 19,20 and 22) shows a clear short-fall at  $\log L/L_{\odot} = -4.2$ , and predicts a larger number of WDs per unit volume, as compared with previous determination of the LF. Knox et al (1999) compared their LF with two sets of stellar models, by Wood (1992) and Garcia-Berro et al (1997). The best fit is obtained using Wood (1992) models, and provides a disk age of  $9.0 \pm 1.0$  Gyr. Garcia-Berro et al (1997) models do not fit the LF maximum, and provide a somewhat greater age.

## 2.2. THE HIPPARCOS CMD

The CMD provided by Hipparcos satellite includes stars within about 150 parsecs from the Sun (see Fig. 2). It shows a well defined MS, a prominent clump of He-burning stars and a subgiant region. It represents of course a mix of stellar populations with spreads in age and in metallicity. The dating features used by Jimenez et al (1998) is the red envelope of the sub-giant region, and the methods adopted is the isochrone fitting one. Since the metallicity of the stars is not known - say from observations - the authors assume that the spread in color of the clump is a good indicator of a spread in metallicity. This is a rather crude approximation, as discussed by Girardi (this meeting). Nevertheless, it is possible to obtain a minimum age for this sample, assuming that the star populating the lower red envelope of the subgiant region has the maximum metallicity, since this metallicity provides the minimum age. So doing they obtain a minimum age for the disk of 8 Gyr.

## 2.3. NEARBY $F$ & $G$ STARS

Another method - although rather difficult - is the direct age estimate of single stars, like the 187 stars sample of Edvardsson et al (1993). To get an age estimate one needs star photometry, spectroscopy and distance, to put them in the  $M_V - \log T_e$  plane. In the case of the Edvardsson et al sample ages are inferred on the Vandenberg scale (1985). Removing from the sample the presumed thick disk stars, or stars whose orbital motions are not that of thin disk stars, a reasonable estimate for the age of the local galactic disk is 9 – 11 Gyr. Recently the Edvardsson et al sample has been revised by Ng & Bertelli (1997), who re-computed the ages of those stars taking into account new distances from Hipparcos, correcting for the Lutz-Kelker effect, and putting them in the Bertelli et al (1994) scale. At older ages the new ages are slightly older, but the conclusion on the disk

age is roughly the same.

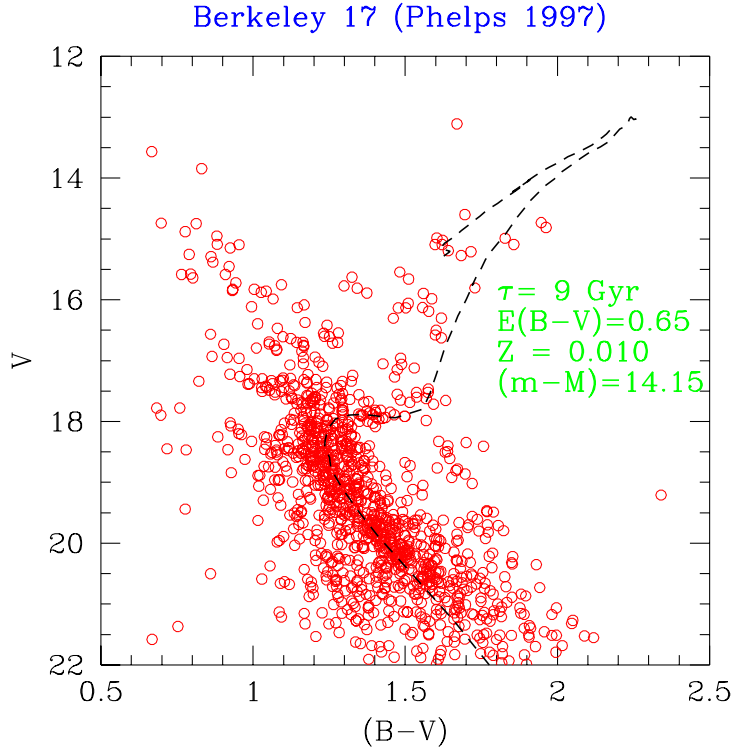
#### 2.4. THE RADIO-ACTIVE CLOCK

Butcher (1987) proposed to derive the age of the Galaxy by observing the radio-active nuclide  $^{232}\text{Th}$  in stars of different ages, and relating the nucleosynthesis timescale to the stellar and galactic evolution. He considered the evolution of Nd, a stable nuclide and Th (half life 14 Gyr). The first point to stress is the extreme weakness of the spectral features in the measured stars spectra: in particular the Th line falls in a blend with Co. The errors related to the derived abundance are around 0.1 dex. The idea underlying this method is that after its formation, a stars does not modify its envelope abundances of Th and Nd but for radio-active decay. By measuring the ratio of the abundances of these elements,  $[\text{Th}/\text{Nd}]$  in stars of different age, it is possible to reconstruct the decay evolution of Th. The basic assumption is that the growth rate of the two elements is the same, although Th is a r-process and Nd is partly a r- and partly a s-process. So doing, they conclude that no reliable chemical evolution model can account for this distribution without assuming an age less than 9 Gyr. The same result has been obtained by Morell et al (1992) who made a new abundance analysis on the same sample.

Clayton (1988) criticized these results, stressing that although the precise nature of r- and s- process is not clear enough, in principle one has to take into account their different evolution. In particular assuming that the contribution to the Nd abundance is about half from r- and half from s-processes, he showed that a simple model of chemical evolution can account for the Butcher distribution assuming ages greater than 12 Gyr, and concluding: *"An unbiased look at all methods together favours an age greater than 12 Gyr, although no single method is reliable. I point out that each nuclear method is still amenable to further improvements, but they alone will not be able to determine the Galaxy's age. Only a detailed and specific and correct model for the growth and chemical evolution of the solar neighbourhood can enable the galactic age to be inferred from radioactivity."*

#### 2.5. OLD OPEN CLUSTERS

Old open cluster are well suited to address many issues concerning our disk (Friel 1995, Carraro et al 1998). For the present topic, they are in principle more suitable than the other indicators to derive a lower limit for the age of the galactic disk. In fact they are distributed in a larger portion of the disk. Good data have been obtained recently for clusters older than M 67, so it is actually feasible to use this sample to determine the age of the disk.



*Figure 3.* The CMD of Berkeley 17 from the V,I photometry of Phelps (1997). Overimposed is an isochrone from Girardi et al 1999 for the parameters listed in the plot.

However there is still debate on the role of the oldest open cluster. NGC 6791, often quoted as the oldest cluster (8-9 Gyr, Carraro et al 1999c), is a rather special object. Its nature is not completely clear, and somebody is suggesting that it could be a bulge globular pushed away by the bar, or the core of a dwarf spheroidal tidally stripped by our Galaxy (see Carraro et al 1999a for a detailed analysis on this cluster). Recently another cluster came out to be very old, Berkeley 17 (Fig. 3). It is actually quite old, with an age around 9 Gyr (Carraro et al 1999b), although optical photometry is not very good yet, and should be improved, being this cluster so important. If Berkeley 17 marks the age of the disk, its minimum age is around 9 Gyr. However the main drawback of open clusters is that their average lifetime is of the order of some  $10^8$  yr (Grenon 1990), so many old clusters might

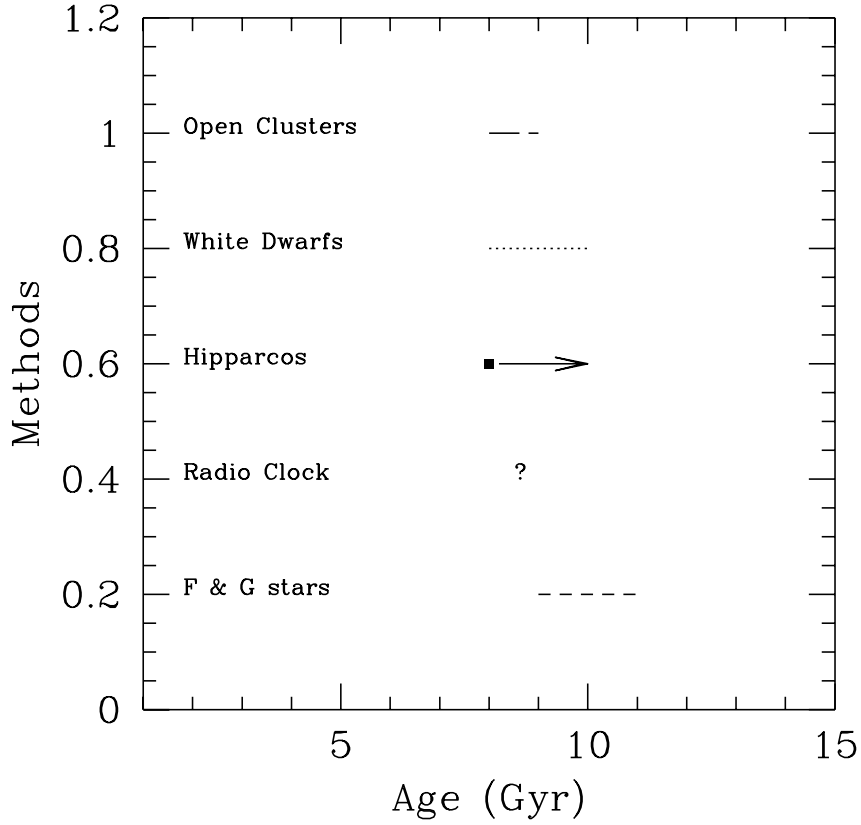


Figure 4. Summary of disk ages from different methods.

have been destroyed. Therefore the statistics of old open clusters is rather poor, and in principle they can provide only a lower limit for the age of the thin disk (Carraro et al 1999c). Anyhow their dating is rather simple and robust.

### 3. Conclusions

In the past several reviews were dedicated to the disk age issue. I would like to remind the reviews from Sandage (1990), van den Bergh (1990) and Grenon (1990).

Sandage at the 1989 Kingston Conference in Canada concluded that the disk overlaps in age the halo, whereas van den Bergh, at the same meeting, suggested that the disk is somewhat younger than the halo.



Obviously the question of a possible star formation delay at the end of the halo assembly depends on the age of the halo, and on the age of the disk. The age of the halo comes from the mean globular clusters age (12 – 15 Gyr at that time), whereas the age of the disk comes from a variety of methods, going from old open cluster to white dwarfs, from radioactive decay to stars in the solar neighbourhood. At that time the oldest open cluster was NGC 6791, with an age around 12 Gyr according to Sandage, who quoted Janes (1988), and of 7 Gyr according to van den Bergh, who quoted a preliminary work by Demarque et al (1992).

The conclusion of van den Bergh is supported also by Grenon (1990), who in addition stressed that in the solar vicinity there is a group of metal rich stars which seem to be older than open clusters, but whose birthplaces might be inside the bulge.

Ten years after the situation is not much different.

Gratton et al (1997) reported a mean age of the bulk of the halo globulars around 13 Gyr, which holds for all the halo clusters. There is indeed the evidence of a population of very young globulars (Pal 12 for instance), whose belonging to the halo is controversial.

Summarizing all the data I discussed above (see also Fig. 4) a plausible age for the disk is in the range 8 – 10 Gyr. Note that the age scale in the case of F & G stars and open clusters is the same as for globulars.

This seems to suggest the occurrence of a hiatus, or minimum in the star formation history of the Galaxy, which might reflect the end of the halo/bulge formation. Afterwards the Galaxy started to acquire material to form the disk in an inside-out scenario.

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